

# On the origin of drifting phenomenon in pulsars

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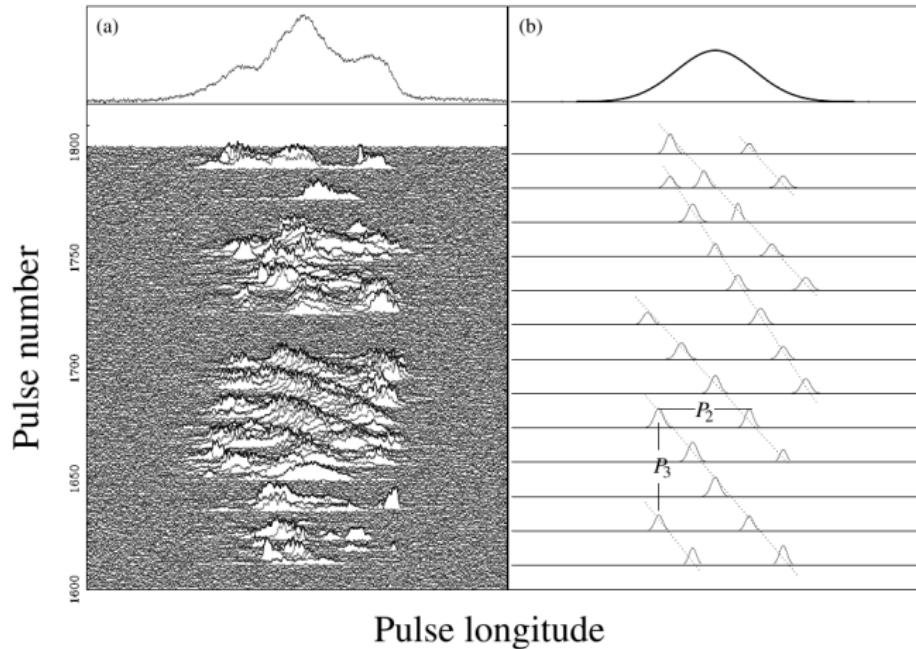
# Outline

- Theoretical background
  - The carousel model
  - Polar cap physics
- The numerical model
  - Bi-drifting pulsars
  - Results
- An alternative model?

# Drifting subpulses

Discovered by Drake & Craft (1968)

The individual pulses consists of **subpulses** which, in many cases, exhibit **systematic variation in position or intensity or both**.

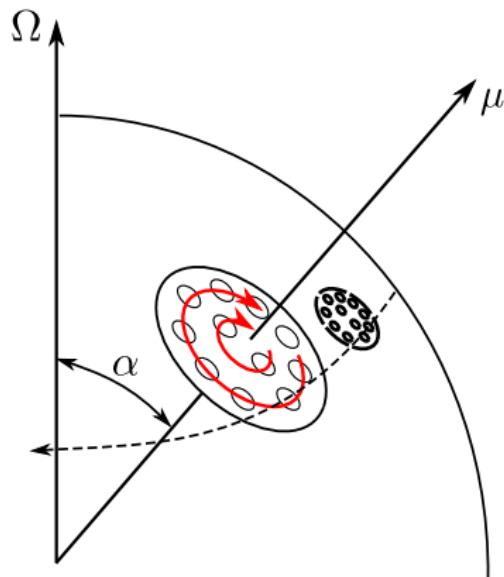


Taken from "Handbook of Pulsar Astronomy" by Lorimer & Kramer.

# The carousel model

(Ruderman & Sutherland, 1975)

A group of localized discharges ("sparks") circulate around the magnetic pole of the neutron star.



In parts of the polar cap sparks move faster than the corotation

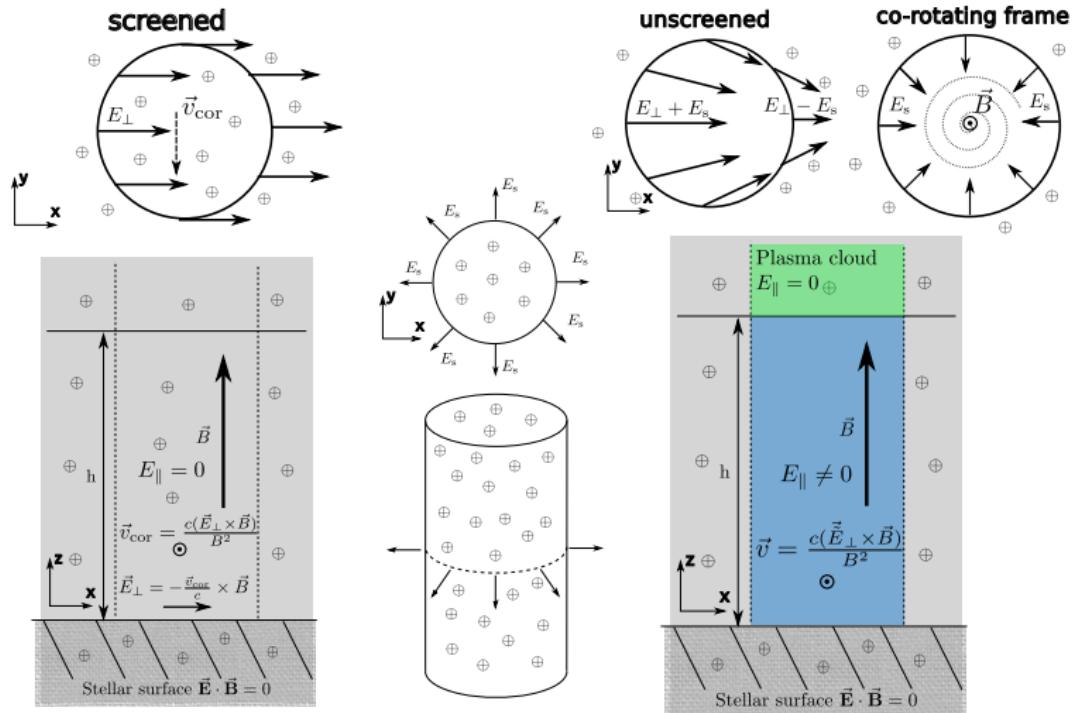
The  $\mathbf{E} \times \mathbf{B}$  drift is around the rotation axis not the magnetic axis!

For the non-dipolar structure of surface magnetic field the magnetic axis may be beyond the polar cap

The carousel model can explain variety of pulsar data (e.g., Gil & Sendyk 2000; Gil & Mitra 2001; Gil et al. 2003; Weltevrede et al. 2006, 2007; Herfindal & Rankin 2007; Rankin & Wright 2008; Herfindal & Rankin 2009, ...).

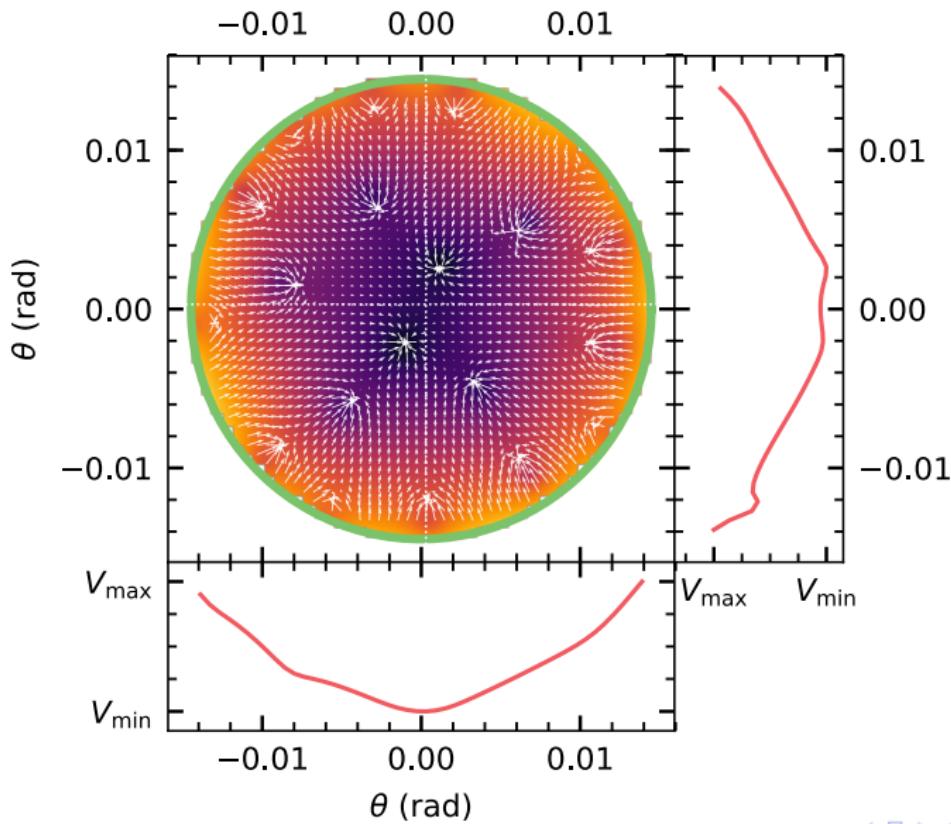
# Spark forming region

(Szary & van Leeuwen, 2017)



The electric and magnetic fields within a region of spark formation with screened acceleration (the left panel) and during the discharge (the right panel).

# Electric field at the polar cap



The electric field (the white arrows) across the polar cap for random distribution of sparks. The color map corresponds to the electric potential.

The electric potential of a single spark:

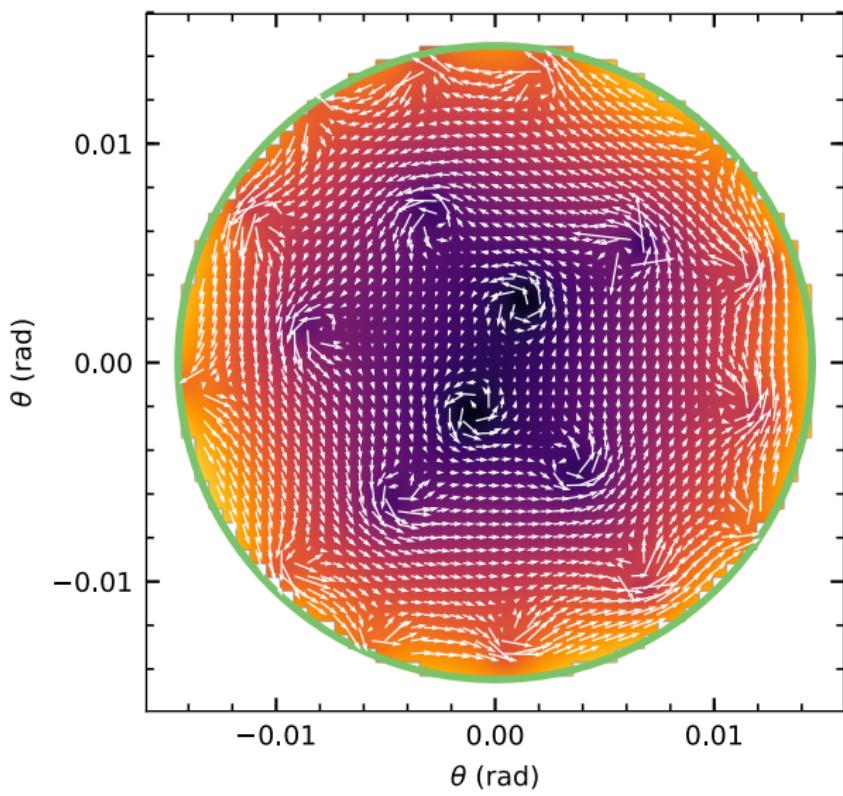
$$V' \propto \ln(r_s)$$

$$\tilde{\mathbf{E}}'_\perp = -\nabla V'$$

The drift velocity:

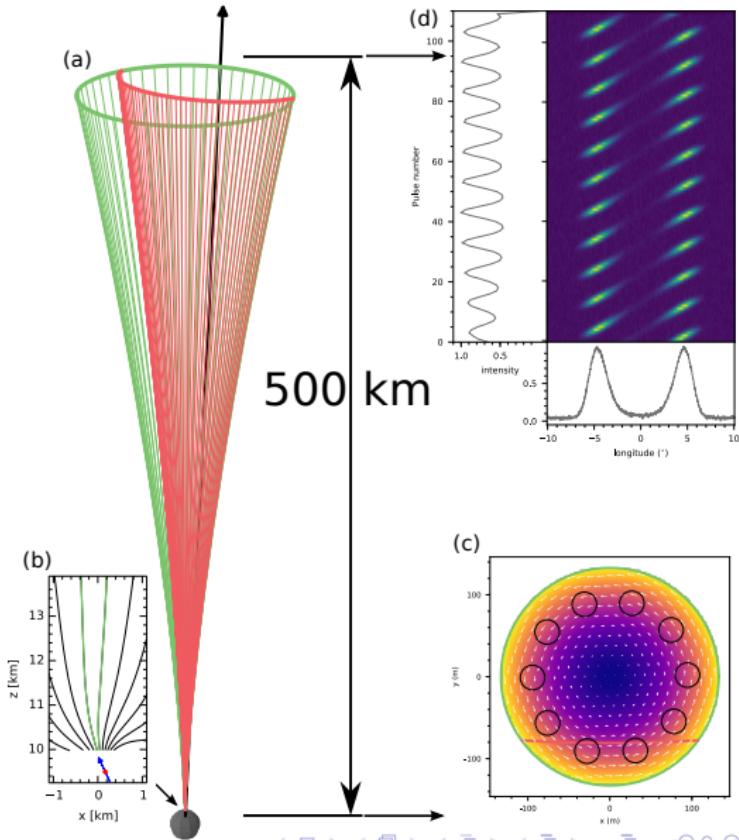
$$\vec{v}_{\text{dr}} = \frac{c(\tilde{\mathbf{E}}_\perp \times \vec{\mathbf{B}})}{B^2}$$

# Plasma velocity at the polar cap



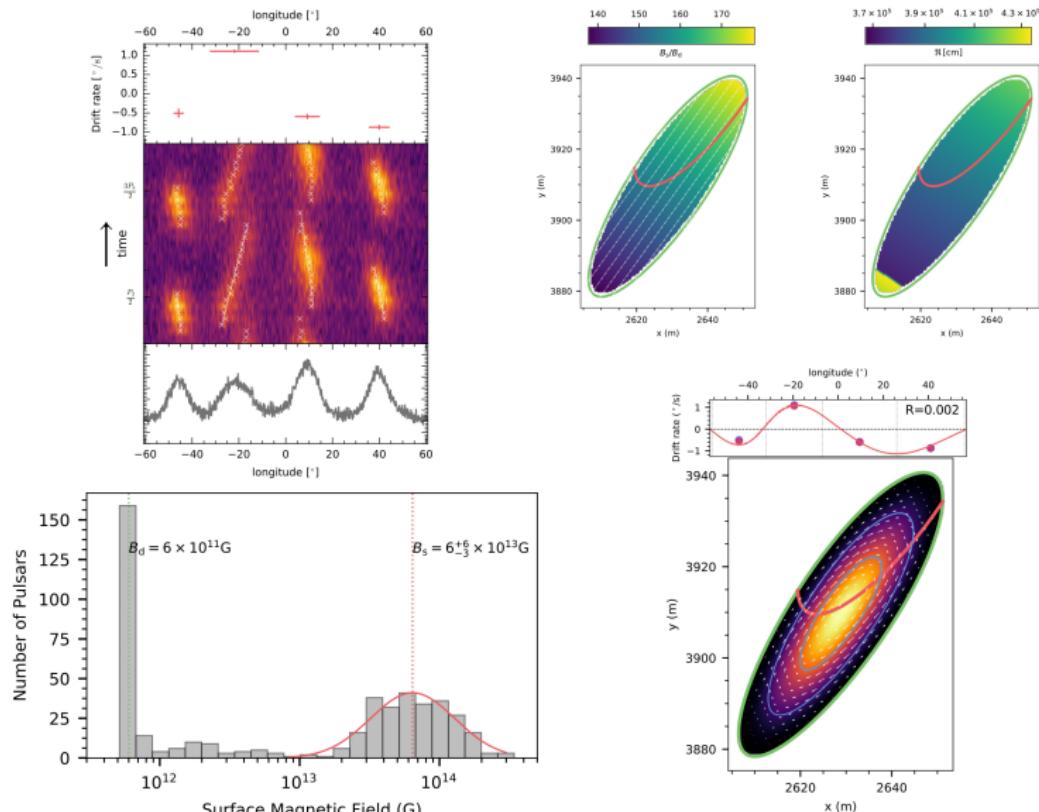
# The numerical model

- neutron star setup (pulsar geometry, magnetic field configuration)
- calculation of open magnetic field lines and lines connected to the line of sight (a, b)
- electric potential setup (c)
- simulation of sparks motion at the polar cap (c) and modelling of single pulses (d)



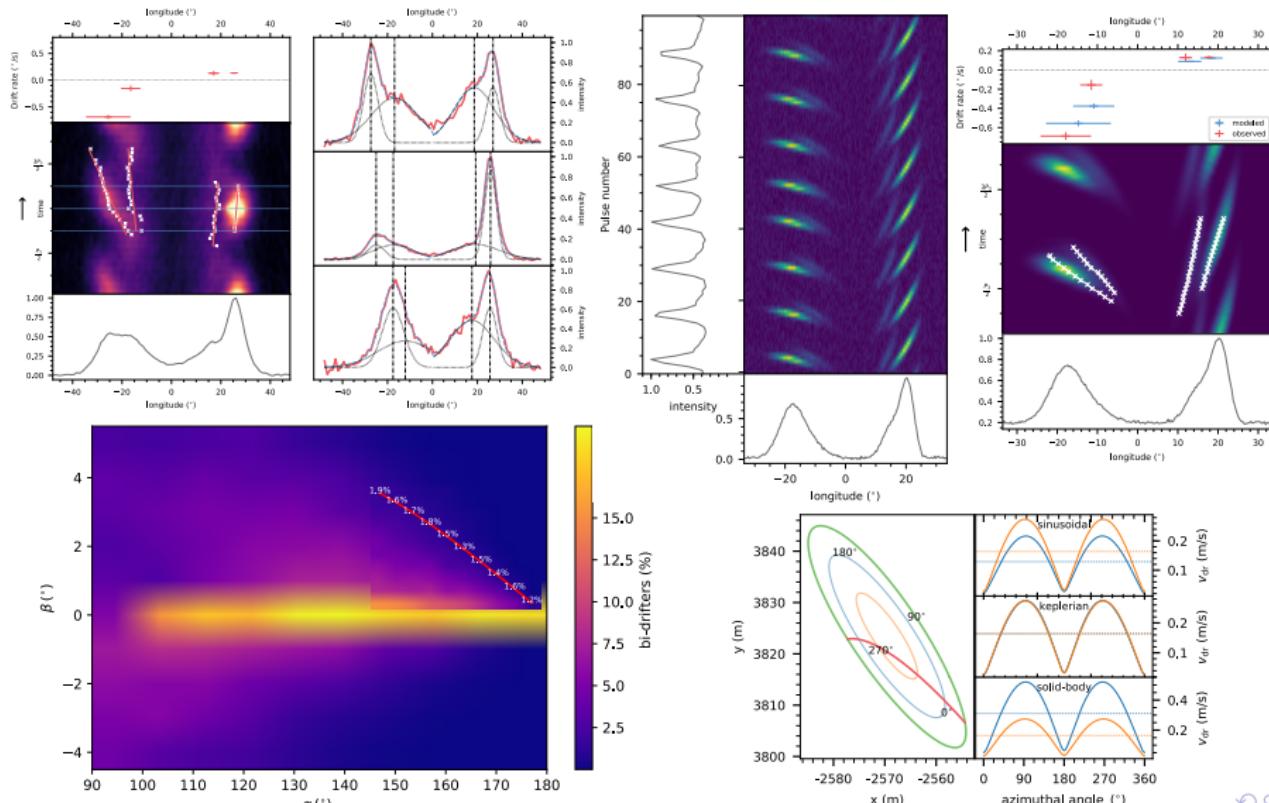
# Bi-drifting phenomenon in PSR J0815+0939

(Szary & van Leeuwen, 2017)



# Bi-drifting phenomenon in PSR B1839-04

(Szary, van Leeuwen, Weltevrede, & Maan, submitted to ApJ)

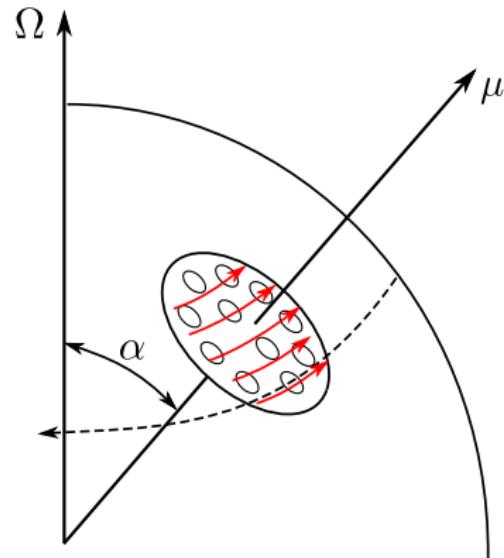


# The modified carousel model

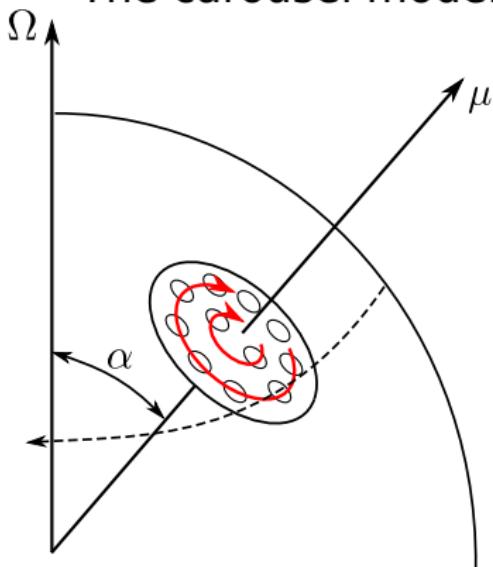
- Plasma between spark forming regions rotate around the electric potential extremum (minimum or maximum) at the polar cap.
- The location of spark forming regions (sparks) is determined by plasma between sparks.
- The modified carousel model provides physical insight into the polar cap region (surface magnetic field, electric potential variation).
- "The drift velocity depends [...] on the variation of the accelerating potential across the polar cap" (van Leeuwen & Timokhin, 2012)

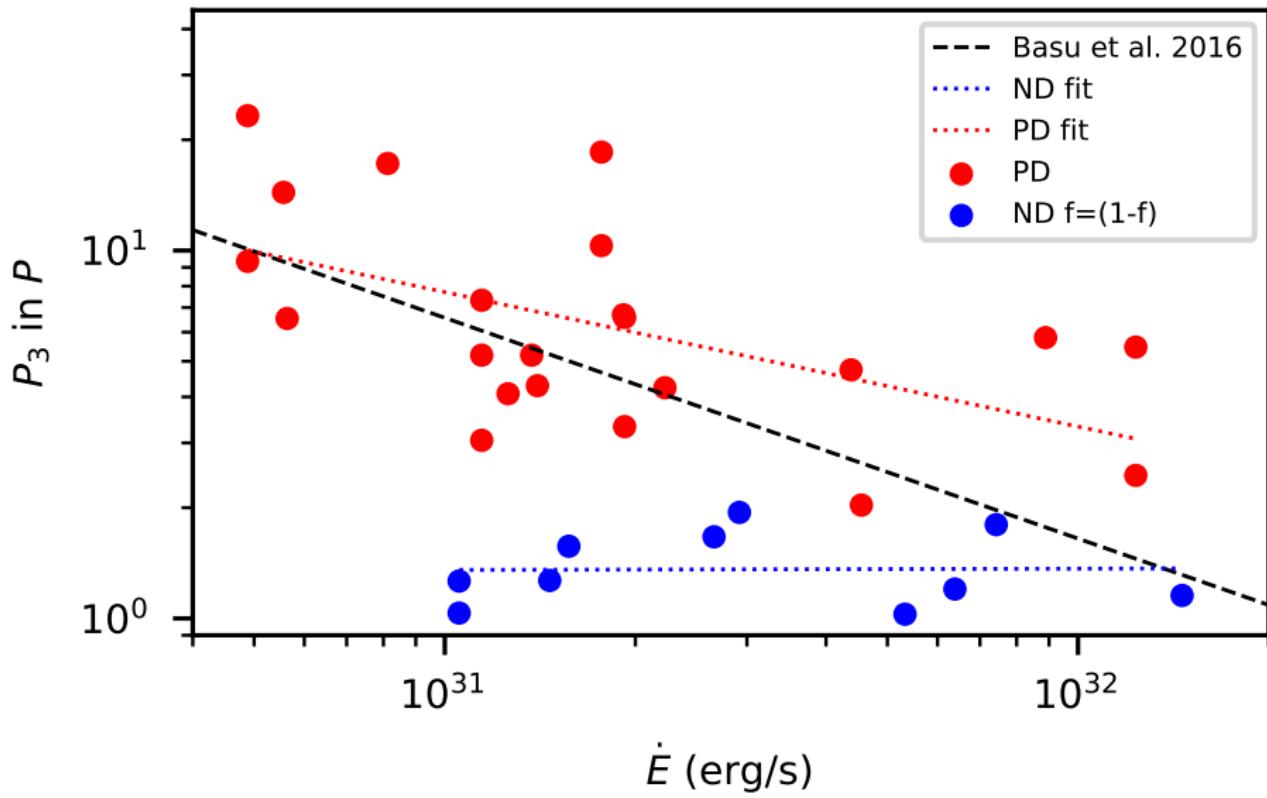
# An alternative model?

The corotation model



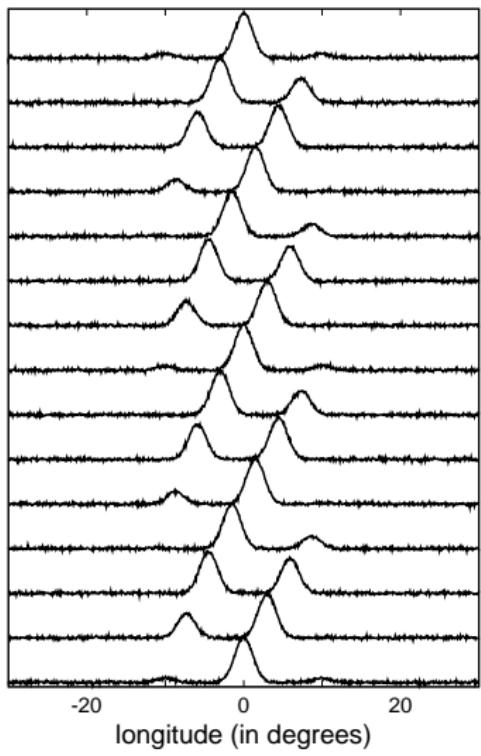
vs The carousel model



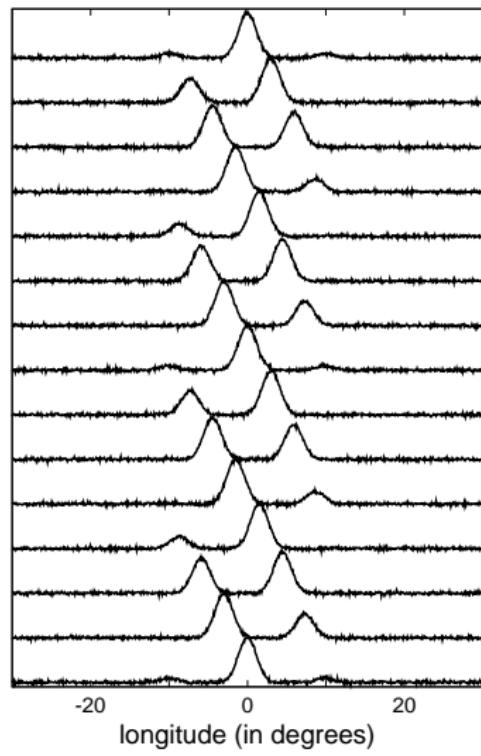


# Drift direction

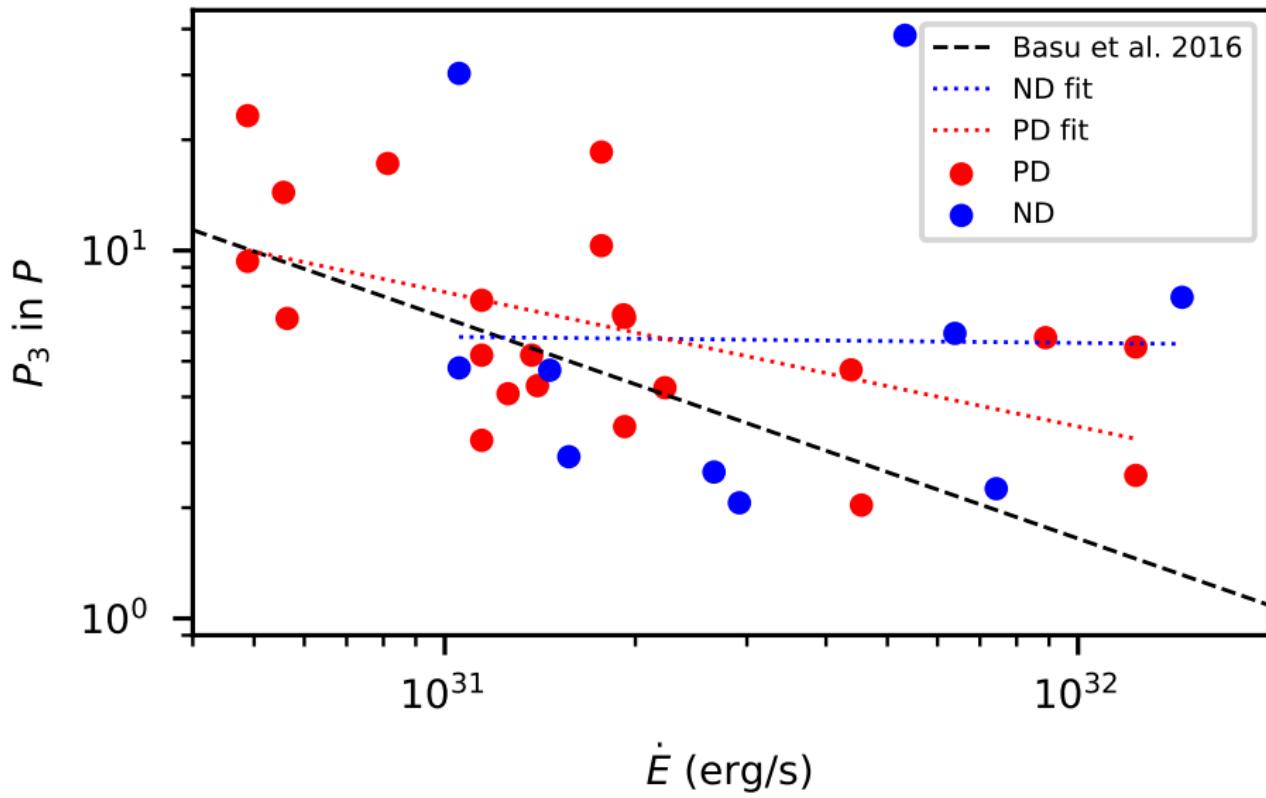
positive drift



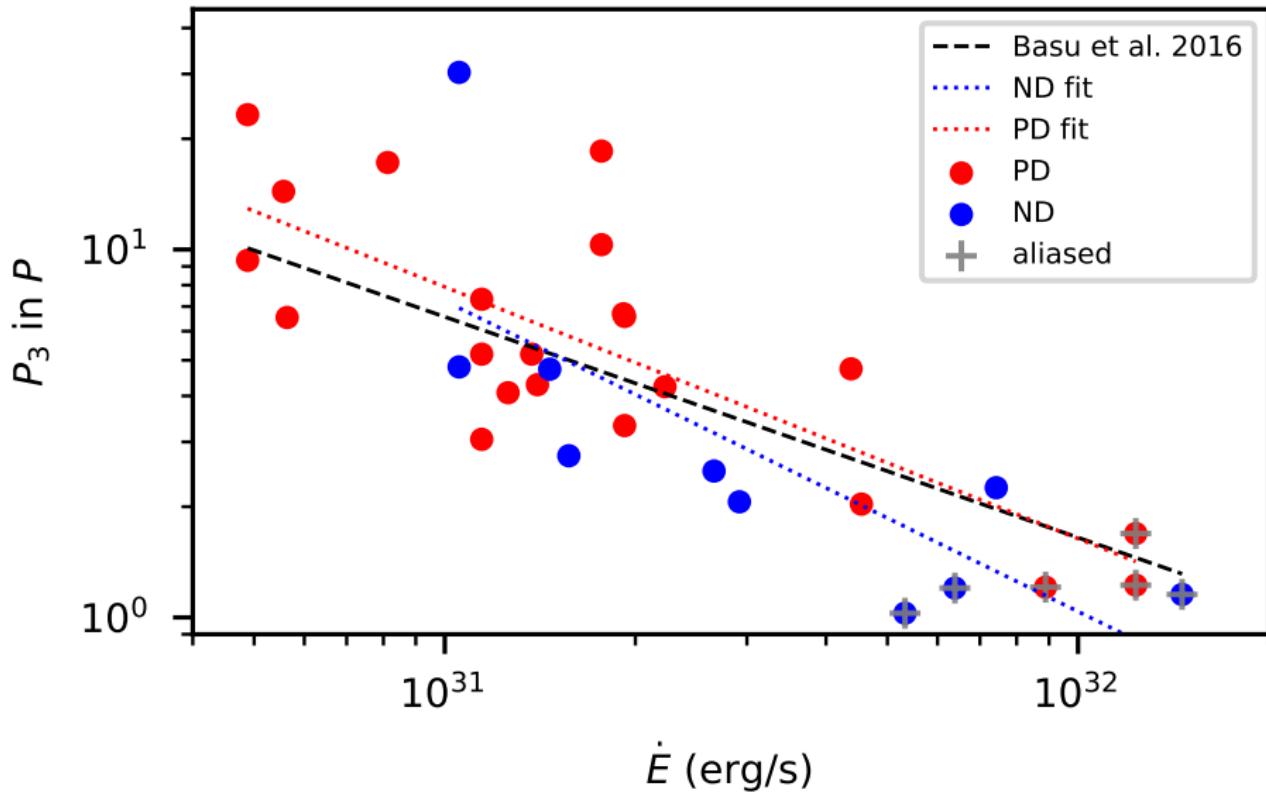
negative drift



# $P_3(\dot{E})$ - raw data



# $P_3(\dot{E})$ - the modified carousel model



## Hypothesis

Plasma in the open field line region can be described as multiple-vortex electromagnetic tornado.



The faster the tornado rotates, the faster the pulsar loses its spin-down energy.

# Thank you!



Netherlands Organisation for Scientific Research

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